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RESEARCH IN THE AREA OF THERMAL MEASUREMENTS (SELECTED ARTICLES--ETC(U)
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RESEARCH IN THE AREA OF THERMAL MEASUREMENTS
(SELECTED ARTICLES)

FOREIGN TECHNOLOGY DIVISION

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UNEDITED MACHINE TRANSLATION

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RESEARCH IN THE AREA OF THERMAL MEASUREMENTS (SELECTED ARTICLES)

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	α	Nu	Ν	ν	
Beta	Β	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	Ο	ο	
Delta	Δ	δ		Pi	Π	π	
Epsilon	Ε	ε	ϵ	Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ		Sigma	Σ	σ	ς
Eta	Η	η		Tau	Τ	τ	
Theta	Θ	θ	ϑ	Upsilon	Τ	υ	
Iota	Ι	ι		Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ ×	Chi	Χ	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	Μ	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

INSTALLATION FOR [redacted] PRECISION MEASUREMENT[redacted] OF THE COEFFICIENT OF THERMAL DIFFUSIVITY OF THERMAL INSULATORS IN TEMPERATURE RANGE 100-800°C

K. G. Partskhaladze, O. A. Sergeyev, I. M. Frenkel'.

Disagreements of the data on the thermal diffusivity one and the same substances, obtained in different laboratories, are produced by many factors: the lax derivation of design equations, by the nonobservance of the conditions of experimentation, by the different physicochemical composition of the investigated material, by the incorrectness of the measurement of the temperature in specimen/sample, by the incorrect estimation of error in the method etc.

In VNIIM [ВНИИМ - All-Union Scientific Research Institute of Metrology im. D. I. Mendeleyev] is created specimen installation for the certification of the standard specimen/samples of thermal diffusivity.

The accuracy of the measurements of thermal diffusivity can be provided for only when the method is absolute and has precise when the method is absolute and has precise theory, are widely investigated the possible systematic errors of measurement, specimen installation sufficiently correctly realizes the

prerequisite/premises of theory.

It is desirable also in order that method and equipment make it possible to carry out the rapid measurements of the broad class of materials in large temperature range.

During the design of specimen installation, it is necessary to consider that it will operate itself in the extent/elongation of many years, and consequently, will continuously grow/rise the shown for it requirements. In connection with this into installation, must be laid such cell/elements (structural/design assemblies, automatic control systems and the measuring circuits) whose possibilities somewhat exceed contemporary requirements and create the prerequisite/premises of the continuous perfection/improvement of the fundamental technical specifications: the accuracy/precision of measurements, reliability of work, productivity, cost-effectiveness/efficiency etc.

As can be seen from survey/coverage [1-8], which generalize the results of Soviet and foreign investigations occurs the natural selection of methods, into process of which part of the methods turns out to be incapable to satisfy the constantly grow/rising requirements and measurements (methods of the thermal similarity, not limited standard, etc.). This leads to deterioration failure of them, especially in new branches of science and engineering where the rapid

and precision measurements of the physical quantities in wide temperature range have fundamental importance.

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Other methods continuously are improved and transfer/convert to the field classical, since they have detailed theory, confirmed by experiment (quasi-stationary, monotonic heating, temperature waves).

For producing specimen installation, was selected as most theoretically substantiated and virtually reliably realized, the method of quasi-stationary mode/conditions [9] with the system of the corrections, obtained in the theory of monotonic heating [16, 8]. The important role in the selection of method will play rapid obtaining the results of measurements over a wide range of temperatures.

The theory of method.

For the unlimited plate with a thickness $2l$, temperature $t(l, \tau)$ and $t(-l, \tau)$ of surfaces of which are equal and change in time τ according to linear law with a velocity of b, between the center and the boundary it appears a difference in temperatures [9]

$$\vartheta_{max} = -\frac{bl^2}{2a} + \frac{bl^2}{a} \sum_{n=1}^{\infty} \frac{A_n}{\mu_n^2} \exp\left(-\mu_n^2 \mathrm{Fo}\right), \tag{1}$$

where a - coefficient of thermal diffusivity; $\mathrm{Fo} = \frac{a\tau}{l^2}$ — fourier number:

$$\mu_n = (2n-1)\frac{\pi}{2};$$

$$A_n = (-1)^{n+1} \frac{4}{(2n-1)\pi}.$$

With Fo = 0.5 with accuracy/precision 0.25o/o all terms of a series in (1) can be disregarded [9], with the exception of the first (n = 1), i.e.,

$$\vartheta_{max} = -\frac{bl^2}{2a} + \frac{bl^2}{a} \cdot \frac{16}{\pi^3} \exp\left(-\frac{\pi^2}{4}\mathrm{Fo}\right), \tag{2}$$

or

$$\vartheta_{max} = -\frac{bl^2}{2a}(1+\delta_1), \qquad (3)$$

where

$$\delta_1 = \frac{32}{\pi^3}\exp\left(-\frac{\pi^2}{4}\mathrm{Fo}\right). \qquad (4)$$

Thus, usually the utilized in the methods of quasi-stationary mode/conditions working formula

$$a = -\frac{bl^2}{2\vartheta_{max}} \qquad (5)$$

is not a precise in the initial period due to effect irregular stage cf mode/conditions.

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As shown in [8, 16], during the derivation of this formulas is not considered the effect of the temperature dependence of thermophysical values, asymmetry of temperature field, limitedness of the size/dimensions of plate and series of other factors. In its general view can be presented as

$$a_0 = -\frac{bl^2}{2\vartheta_{max}}(1 + \delta_1 + \delta_2' + \delta_2'' + \delta_3 + \delta_4 + \delta_5 + \delta_6), \qquad (6)$$

where δ are corrections, and index 0 means that the values of the

corresponding quantities are related to the temperature of the surface of plate.

The correction of δ'_2 is introduced [10] in connection with the account of the effect of the temperature dependence of thermophysical values

$$\delta_2' = \vartheta_{max}\left[\frac{5}{6}(k_b + k_c + k_\gamma) - \frac{k_\lambda}{2}\right], \qquad (7)$$

where the k_c, k_γ, k_λ, k_b - the temperature coefficients of the specific heat c, of density γ, of the coefficient of thermal conductivity λ, and also of the velocity of heating b in plane x = 0. The values of the low parameters of k_c, k_γ and k_λ usually are taken from reference data. The parameter of k_b is determined from formula

$$k_b = \frac{b_i - b_0}{b_0} \cdot \frac{1}{\vartheta_{max}}.$$

Here b_i are the variable speed of the heating of plate in section x

= 0 at torque/moment τ_1. It is located by differentiation with respect to time of the obtained in the process of the heating experimental dependence t (0, τ) = f (τ), which after statistical processing is represented in the form of polynomial

$$t(x,\ \tau)|_{x=0} = c_1 + c_2\tau + c_3\tau^2 + \cdots$$

Hence

$$b_i = \frac{dt(x,\ \tau)}{d\tau}\bigg|_{x=0} = c_2 + c_3\tau + \cdots$$

Correction δ''_2 more precisely formulates δ'_2 by means of the account of terms of expansion, who contain the low parameters of the second order of smallness [10]

$$\delta''_2 = \vartheta^2_{\max}\left\{\left[\frac{5}{6}(k_b + k_c + k_\gamma) - \frac{k_\lambda}{2}\right]^2 + \right.$$
$$\left. + \left[\frac{61}{90}(k_b^2 + k_c^2 + k_\gamma^2) - \frac{k_\lambda^2}{2}\right]\right\}. \qquad (8)$$

When no sufficient reliable data on the thermophysical properties of the investigated material, for the calculation of corrections (7) and (8) it is possible to use relationship/ratio [8]

$$k_a = k_\lambda - k_c - k_\gamma,$$

where k_a — the relative coefficient of a change in the thermal diffusivity. For its determination is analyzed dependence a = ϕ (T), calculated in zero approximation according to formula (5).

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After carrying out one substitution or the other from this relationship/ratio, we will obtain other expressions of corrections (7) and (8)

$$\delta_2' = \vartheta_{\max}\left[\frac{5}{6}(k_b - k_a) + \frac{1}{3}k_\lambda\right];$$

or ~~или~~

$$\delta_2' = \vartheta_{\max}\left[\frac{5}{6}k_b - \frac{1}{2}k_a + \frac{1}{3}(k_c + k_\gamma)\right];$$

$$\delta_2'' = \vartheta_{\max}^2\left[\frac{247}{180}(k_b^2 - k_a^2) + \frac{61}{45}k_c^2 + \frac{13}{45}k_\lambda^2 - \frac{25}{18}k_b k_a + \right.$$
$$\left. + \frac{5}{9}k_b k_\lambda - \frac{86}{45}k_a k_\lambda - \frac{61}{45}(k_\lambda k_c - k_a k_c)\right],$$

or ~~или~~

$$\delta_2'' = \vartheta_{\max}^2\left[\frac{247}{180}(k_b^2 - k_a^2) + \frac{61}{45}k_\gamma^2 + \frac{13}{45}k_\lambda^2 - \frac{25}{18}k_b k_a + \right.$$
$$\left. + \frac{5}{9}k_b k_\lambda - \frac{86}{45}k_a k_\lambda - \frac{61}{45}(k_\lambda k_\gamma + k_a k_\gamma)\right],$$

or ~~или~~

$$\delta_2'' = \vartheta_{\max}^2\left[\frac{247}{180}\left(k_b^2 + \frac{13}{45}(k_c^2 + k_\gamma^2) - \frac{1}{4}k_a^2 - \frac{5}{6}k_b k_a + \right.\right.$$
$$\left.\left. + \frac{5}{9}(k_b k_c + k_b k_\gamma) - k_c k_\gamma - \frac{2}{3}(k_c k_a + k_\gamma k_a)\right)\right].$$

Correction

$$\delta_3 = 2\alpha t \quad (9)$$

is introduced [8] due to effect on the results of the measurements of the temperature expansion of specimen/sample (α is a coefficient of linear expansion, t - the temperature of plate).

Correction

$$\delta_4 = \frac{\Delta^2}{l^2} \quad (10)$$

is connected with the possible displacement of heat receiver from plane x = 0 up to distance Δ [8].

Correction δ_5 considers the effect of the lateral heat exchange of plate and it can be designed, for example, acording to the procedure, given on page 242.

Finally, correction δ_6 is introduced due to the possible asymmetry of temperature field, which is expressed in the fact that if $\vartheta(l, \tau) = 0$, then $\vartheta(-l, \tau) = \Delta U$. The solution to equation

$$\frac{d^2\vartheta(x, \tau)}{dx^2} = \frac{b}{a}$$

in these boundary conditions leads to expression

$$a_0 = -\frac{b_0 l^2}{2\vartheta_{max}}\left(1 + \frac{\Delta U}{2\vartheta_{max}}\right),$$

~~г.е.~~ i.e.

$$\delta_6 = \frac{\Delta U}{2\vartheta_{max}}. \quad (11)$$

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Installation consists of high-temperature furnace (Fig. 1) and the bench of measurement and automatic control (Fig. 2).

The construction of furnace is schematically shown in Fig. 3. It is table type device, which involves the systems of heating, the compression of specimen/sample and heat shield. Investigated specimen/sample 6 and guard ring 7 are establish/installed between disk low-inertia heaters 8. Each heater has two cell/element from Nichrome of brand Kh20N80. The internal surfaces of the metallic (copper, steel or nickel) disks of heaters contact with the external surfaces of specimen/sample.

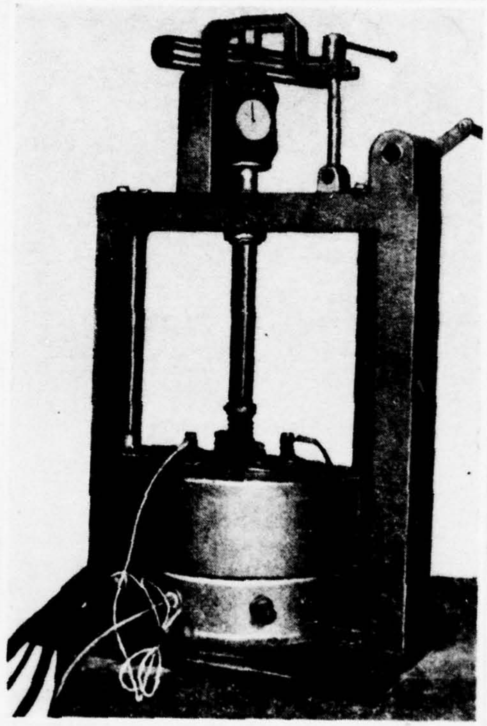

Fig 1.

Fig. 1. High-temperature furnace.

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A decrease in the gradient of the temperature in radial direction serves the system of screens 9 of the polished stainless steel. The measurements will show that as a result of the accepted measures in the middle zone (50 mm in diameter) of the surfaces of the heaters of a difference in the temperatures on surfaces do not exceed 0.2 deg with 200°C (copper), 0.4 deg with 500°C (copper, steel, nickel) even 0.6 deg with 800°C (steel, nickel). The delay of the peripheral thermocouple of specimen/sample relative to the torque/moment of a change in the power of heating elements does not exceed 5 s.

For the protection of melting chamber from the effect of environmental factors (air circulation in room, the thermal radiation of the surrounding object/subjects etc.) and of cooling the external surface of furnace in dual jacket 3, is established/installed copper coil 4 on which through the manostat witl constant pressure head is passed the water. The reliable adjustable contact of specimen/sample 6 and of guard ring 7 with heaters 8 is realize/accomplished with the aid of the system of the compression of specimen/sample 5, which involves dynamometer DOSM-3-0.2, and specimen indicator.

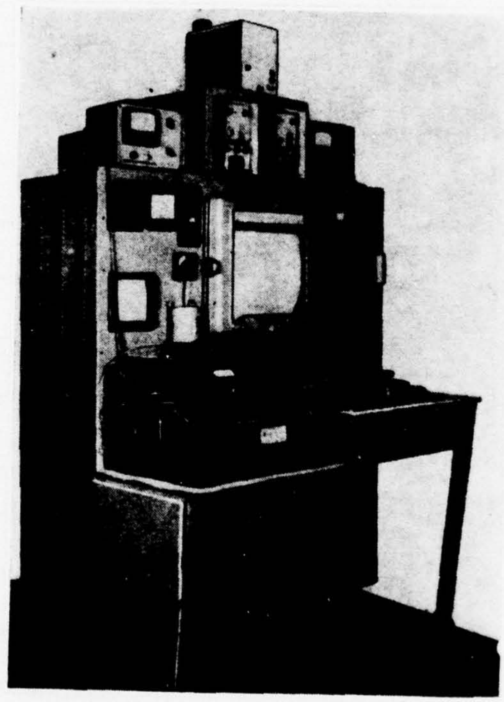

Fig. 2

Fig. 2. Bench of measurement and automatic control.

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System makes it possible to assign force of compression from 0 to 2000 n (≈200 kgf) with error ±2.5 n. For the input/introduction of heat receivers 2 into the jacket of furnace, are provided for the opening/apertures, closed against heat-resistant rubber 1. Installation makes it possible to investigate specimen/samples up to 150 mm in diameter and with a thickness to 22 mm.

The construction of specimen/samples is schematically shown in Fig. 4. Are applied two form of specimen/samples. For the measurement of the thermal diffusivity of glass (Fig. 4a) is utilized the plate in the form of disk, which consists of four plates, connected with the action of the forces of molecular cohesion/coupling (optical contact). Before the installation on optical contact on surfaces, are cut special groove/slots for the laying of thermocouples. This method of the assembly of thermocouples makes it possible to accurately determine the distance between joints (on preliminary measurement the thickress of plates) and to ensure the reliable contact of thermojunctions with specimen/sample. In the case of the measurement of the thermal diffusivity of the materials for which it is not

possible to use the first method of the production of specimen/samples, thermocouple they are laid into the radial opening/apertures of specimen/sample and guard ring (Fig. 4b).

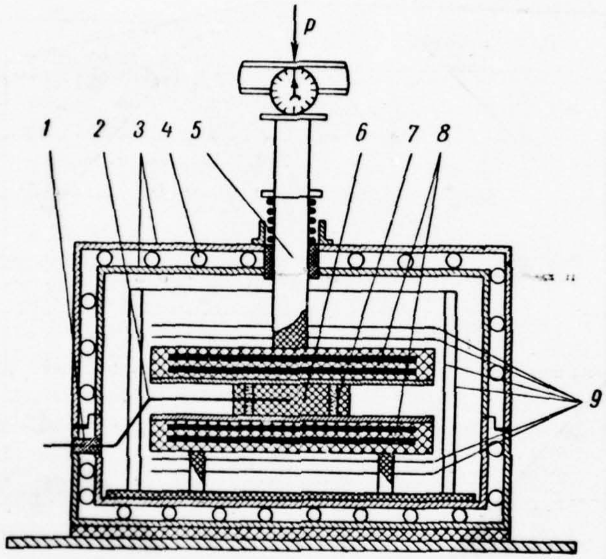

Fig 3

Fig. 3. Diagram of the high-temperature furnace: 1 - rubber stopper; 2 - thermocouple; 3 - dual jacket; 4 - cooling coil; 5 system of the compression of specimen/sample; 6 - test specimen; 7 - guard ring; 8 - disk heaters; 9 - the system of screens.

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For producing the reliable thermal contact of thermojunctions with the investigated material into opening/apertures, is introduced the small amount of grit copper or nickel) or high-temperature cement. The size/dimension l, which enters working formula (6), is determined after experiment (specimen/sample is cut and is measured the distance between centers of radial opening/apertures in the location of joint).

A difference in the temperatures of ϑ_{max} is measured by thermocouples 2 and 3. Thermocouple 4 serves for automatic maintaining heating, and differential thermocouple 1 is for automatic maintaining temperature symmetry. With the aid of thermocouples 2 and 6, is controlled the unidimensionality of temperature field. A difference in the temperatures in points 3 and 5 makes it possible to calculate correction for the asymmetry of heating. The appearance of quartz specimen/sample with thermocouples is represented in Fig. 5.

For the realization of the linear heating of specimen/sample and conditions of the symmetry of its temperature field were developed two automatic control systems (ACS) [CAP], block diagram of which was given in Fig. 6. one of them is intended for the programmed temperature control of the section of specimen/sample $x=l$ in time, and another - for maintaining the equality of the temperatures on surfaces of $x=l$ and $x=-l$ specimen/sample in the process of experiment. Both diagrams are developed according to aggregate (block) [1] principle with the maximum use of series Soviet equipment.

FOOTNOTE [1]. See foreign page 223. ENDFOOTNOTE.

Fig. 4. Constructions of the used specimen/samples: a) from glass and quartz; b) from polymers.

Key: (1). Guard ring. (2). Optical contact. (3). Guard ring.

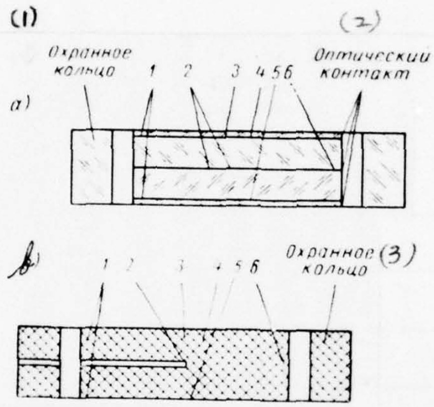

Fig. 4

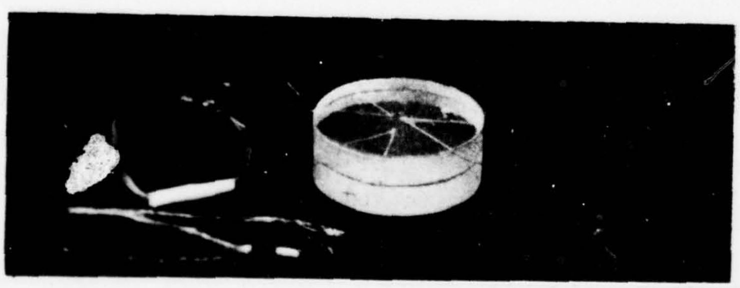

Fig. 5. Quartz specimen/sample with mounted in it thermocouples.

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The diagram of the programmed temperature control works as follows. To the entrance of automatic regulator I, which realizes proportional-integral-differential (PID) control [11], enters the signal about the deviation of temperature of the surface of specimen/sample from that which is required with respect to program. Algebraic subtraction is realize/accomplished because of the contrary connection/inclusion of thermocouple and output signal of the programmed controller.

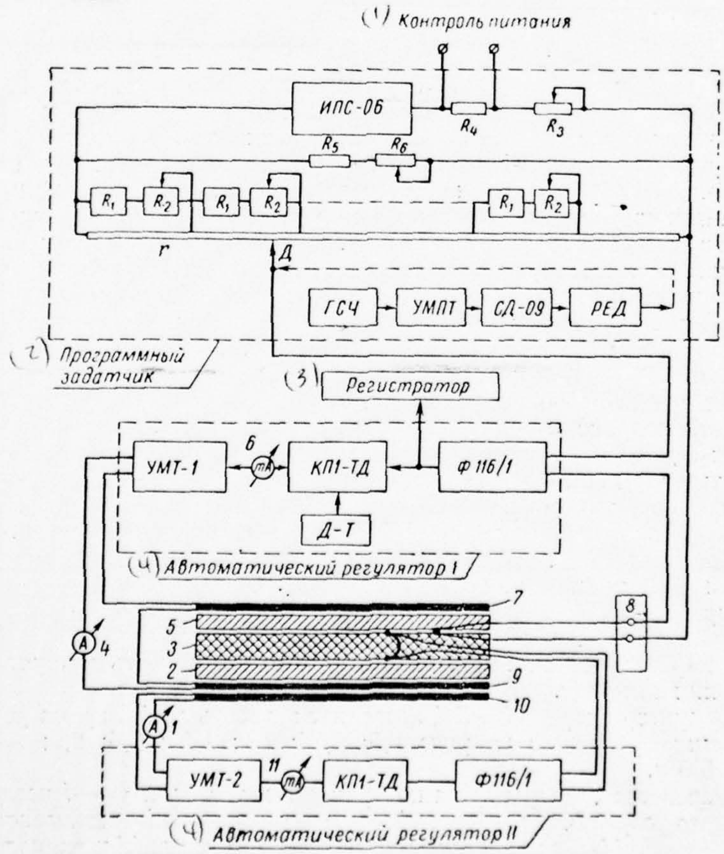

Fig 6.

Fig. 6. The diagrammatic representation of automatic control systems. 1 and 4 - ammeters E421; 2 and 5 - plate for the equalization of temperature field on the surfaces of specimen/sample; 3 - test specimen; 6 and 11 - milliammeters M 4203; 7 and 9 - the heaters of the system of the programmed temperature control of the surfaces of specimen/sample; 8 - Dewar flask; 10 - the heater of the automatic control system of the symmetry of temperature field; IPS-06 - the stabilized power supply.

Key: (1). Monitoring of supply. (2). Programmed controller. (3). Monitor. (4). Automatic regulator.

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Automatic regulator consists of the preamplifier of microvolt-microammeter F116, the corrector KP1-TD [12] and of the differentiator D-T [13], together realizing the PID-law of control, and the thyristor power amplifier [1] UMT-1, designed for 1.5 kW and connected consecutively to governing heating elements 7 and 9.

FOOTNOTE [1]. See foreign page 116. ENDFOOTNOTE.

The programmed controller is carried out in the form of separate block and is specially developed for this diagram (accuracy/precision of series programmed controllers of the type of RU5-01, PD-44UM etc. substantially than lower required for this installation). The basic cell/element of the programmed controller is the multiturn slide wire r on which evenly is moved the arm D. To the end/leads of the slide wire conducted stabilized voltage from the supply of power of the IPS-06 whose value determines the temperature range of the programmed control and is adjusted with the aid of shunt register R_6. The uniform displacement of arm D over slide wire r is realize/accomplished with the aid of the synchronous motor SD-09, the frequency of feeding stress of which is stabilized by crystal oscillator [2].

FOOTNOTE [2]. As the generator of frequency, is used the power unit 372P, released for the printing chronograph of the type of 21-372P. ENDFOOTNOTE.

For the amplification of power output of crystal oscillator up to the value, necessary for the motor SD-09, was developed the

double-contact transistor amplifier of alternating current of UMPT.

For the correction of nonlinear dependence of thermo-emf of thermocouples on temperature is applied the system of variable resistances R_2, which shunt the individual sections of slide wire r. For the limitation of the range of shunting, are provided for resistor/resistances R_1. The amount of shunts and their parameters are designed for programming by the method of the piecewise approximation of the calibration characteristic of platinum-platinum-rhodium thermocouple in the range of temperatures 30-1000°C with the error, which does not exceed 0.05°C. In the case of applying the chromel-alumel thermocouples, calibration characteristic of which is linear, the need for shunting fails.

The reducer of speeds ~~ed.~~ RED[РЕД] makes it possible to assign any time of the realization of program from series 0.5; 0.75; 1.0; 1.25; 1.5; 2.0; 2.5; 3.0; 5.0 h.

The equality of temperatures on surfaces of $x=l$ and $x=-l$ the investigated specimen/sample is supported with the aid of automatic regulator II, temperature-sensitive element of which is the differential thermocouple, and by the controlling organ/control - heating element.

Installation makes it possible to regulate thermal process with deviation from program not more than on 0.1 deg and to support a zero difference in the temperatures on the symmetrical surfaces of specimen/samples with error not more than 0.1 deg. With the disconnection of the drive of the programmed controller, the same diagrams make it possible to stabilize the temperature of specimen/sample with the preservation/retention/maintaining of the symmetry of its temperature field.

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For this case is provided for the hand drive of arm ~~A~~ D of the programmed controller, which makes it possible to establish/install the rated value of temperature with accuracy/precision 0.05 deg.

For ease of handling of diagrams, are provided for indicators 1, 4, 6 and 11, which show the output signal of correctors and thyristor amplifiers. Parameters of the experiment are measured by a potentiometer of the compensative type R308 of class by 0.002 and recording instruments (potentiometer the KS-61 of class 0.5 and millivoltammeter N37 of class 1.5), built in into bench.

The output/yield of installation on the assigned mode/conditions, from torque/moment of which it is possible to carry

out measurements, is caused by the irregular stage of the development of thermal process in specimen/sample an by the transient process of automatic control systems. Time of irregular stage is determined from formulas (3) and (4) and can be checked by the analysis of dependence t (0, τ) = f (τ), obtained from experiment. The transit time of automatic control systems, velocity-dependent of heating and dynamic properties of the adjustable object, is determined experimentally (from readings of preamplifiers F-116) it will turn out to be the approximately equal to time of irregular stage. The losses of the temperature interval of measurements, connected with the introduction installations into mode/conditions, are 50-100 deg from the beginning of the process of heating.

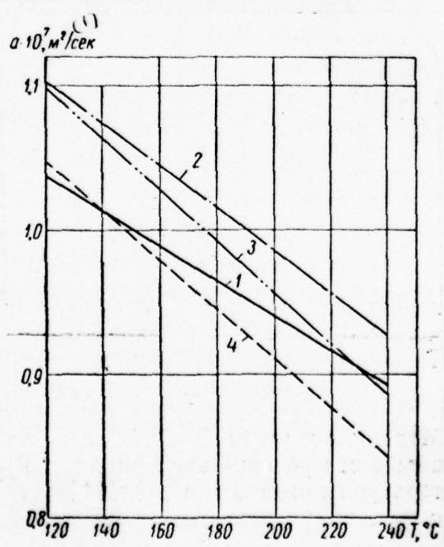

Fig. 7

Fig. 7. Dependence of the thermal diffusivity of polytetrafluoroethylene on temperature according to data: 1 - the authors; 2 - Frayman Yu. Ye. [4]; 3 - Kirichenko Yu. A., Oleynik B. N., Chadovich T. Z. [14]; 4 - Kirichenko Yu. A. [15].

Key: (1). m^2/s.

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Results of measurements and estimation of error in the method.

The calculated error in the method, characterized by the root-mean-square relative measuring error coefficient of thermal diffusivity, is determined from formula

$$\frac{\Delta a_0}{a_0} = \pm \sqrt{\left(\frac{\Delta b_0}{b_0}\right)^2 + 4\left(\frac{\Delta l}{l}\right)^2 + \left(\frac{\Delta \vartheta_{max}}{\vartheta_{max}}\right)^2 + \left(\frac{\Delta P}{1+P}\right)^2},$$

where $P = \delta'_2 + \delta''_2 + \delta_3 + \delta_4 + \delta_5 + \delta_6$ - total correction. The

value of its error is located from expression

$$\Delta P = \pm \sqrt{\Delta\delta_2'^2 + \Delta\delta_2''^2 + \Delta\delta_3^2 + \Delta\delta_4^2 + \Delta\delta_5^2 + \Delta\delta_6^2}.$$

For specimen/samples made of glass and quartz, the calculated error in the method is estimated into ±2o/o. The most ponderable component it is the error of the measurement of a difference in the temperatures of ϑ_{max}. During the investigation of specimen/samples made cf polymers, the calculated error in the method grow/rises to ±5o/o because of the effect of the measuring error of geometric dimension l specimen/sample.

At the created installation was measured the thermal diffusivity cf polytetrafluoroethylene. Investigaticns are carried out on specimen/samples 16 mm in thickness at four different speeds of heating. Measurement data are represented in Fig. 7. Dependence

$$a_0 = (1{,}18 \cdot 10^{-7} \div 0{,}0012 \cdot 10^{-7} \cdot T)\ м^2/s,$$

Obtained as a result of the treatment experimental data by the method of least squares, is depicted as solid line. Root-mean-square error of the results of measurements

$$\sigma_{a_0} = \pm 0{,}008 \cdot 10^{-7}\ м^2/s.$$

The low value of this error testifies to good reproducibility of the conditions of experiment. The disagreements of results with literature data [4], [14] and [15] do not exceed errors of the appropriate methods.

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INSTALLATION FOR [redacted] PRECISION MEASUREMENT[redacted] OF [redacted] THERMAL CONDUCTIVITY OF [redacted] POOR CONDUCTORS OF HEAT.

O. A. Sergeyev, D. A. Tatarashvili.

In VNIIM prolonged time operates itself specimen installation for the measurement of the thermal conductivity of the poor conductors of heat [1].

Temperature interval 300-380°K, in which works specimen installation for the measurement of the thermal conductivity of poor conductors, already insufficient at present, since it does not answer the contemporary requirements for science and engineering. In connection with this will arise the need for producing the specimen installation, making it possible to expand temperature interval into

low-temperature range to 90°K, and in high-temperature range - to 500°K. # For developing installation, was selected the stationary method of the radial heat flux according to which, thermal conductivity

$$\lambda = \frac{q \ln \frac{r_2}{r_1}}{2\pi L\, \Delta t},$$

where q is the power of the basic heater, isolated of section with a length of L m; Δt - a difference in the temperatures between the points, arrange/located at distances r_1 and r_2 from the axle/axis of cylinder.

Cylindrical specimen/sample 4 with guard end-type cylindrical heaters 1 and 9 (Fig. 1) is skirt whose length is 120 mm, inner the diameter of whose which is 4 mm, and external -40 mm.

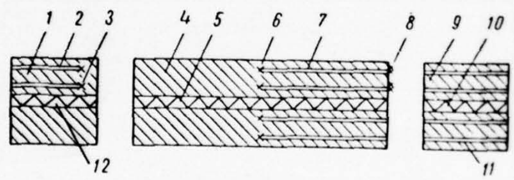

Fig. 1. Diagram of specimen/sample with the guard cylinders: 1 - cylinder; 2 - channels; 3 - thermocouple; 4 - specimen/sample; 5 - heater; 6 - copper-constantan thermocouples; 7 - channel; 8 - supplementary thermocouples; 9 - cylinder; 10, 12 - guard heaters; 11 - through channels.

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In the central opening/aperture of specimen/sample, is placed basic heater 5, made from constantan lead/duct 0.2 mm in diameter, wound up around the ceramic tube 3.6 mm in diameter. The current and potential derivations of the basic heater are made from copper wire 0.2 mm in diameter. For the measurement of the temperature in channel 7, it is installed eight copper-constantan thermocouples 6, arrange/located in pairs along four radial mutually perpendicular directions. Supplementary thermocouples 8 serve for the monitoring of the leakages of heat in terms of the electrodes of measuring thermocouples 6. The electrodes of all measuring and supplementary thermocouples are derive/concluded through the through channels of 11 cylinders 9.

The leakages of heat in axial direction are compensated for with the aid of guard cylinders 1 and 9. In the reactor thimbles of 2 cylinders 1, are placed control thermocouples 3. Are analogously placed control thermocouples in guard cylinder 9. On the absence of the leakages of heat in axial direction, testifies a zero difference in the temperatures between control and measuring thermocouples. Leakages are compensated for by guard heaters 10 and 12.

Installation consists of three basic parts: the chamber of

cryostat (Fig. 2), of vacuum system (Fig. 3) and of measuring bench (Fig. 4).

The measurement procedure is determined as a result of the investigation of the possible systematic errors.

In the process of investigations, are reveal/detected the heat dissipation of the basic heater, caused by the convection of helium in the clearances between the basic heater and the internal opening/aperture of cylindrical specimen/sample. These losses lead to the error to 1.5o/o which completely is removed after the sealing/pressurization of internal opening/aperture with the placed in it heater.

Fig. 2. Chamber of the cryostat: 1 - tube made of the stainless steel for the evacuation of air and derivation of electrodes; 2 - the copper packing ring; 3 - upper lid made of teflon; 4 - the specimen/sample of the investigated material; 5 - the basic heater; 6 - the copper housing with background heater, employed for a derivation system to different temperature levels; 7 - vacuum-sealed brass beaker; 8 - bottom cap/cover from teflon; 9 - Dewar flask for liquid nitrogen; 10 - the housing of Dewar flask; 11 - guard cylinders with heaters.

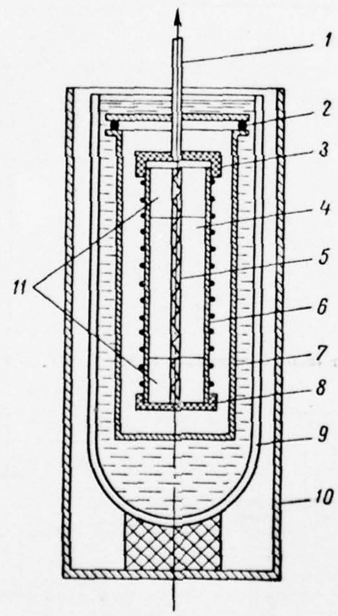

Fig. 2.

Fig. 3. Diagram of the vacuum system: 1 - the chamber of cryostat; 2 - vacuum gauge VIT1A; 3 - rubber tube for maintaining constant pressure in the chamber of cryostat; 4 - cylinder with helium gas; 5 - pre-cylinder; 6 - fore pump VN-461M; 7 - diffusion oil-vapor pump TsVL-100; 8 - nitrogen trap.

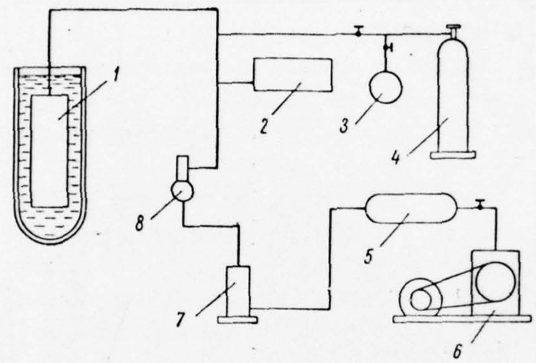

Fig. 3

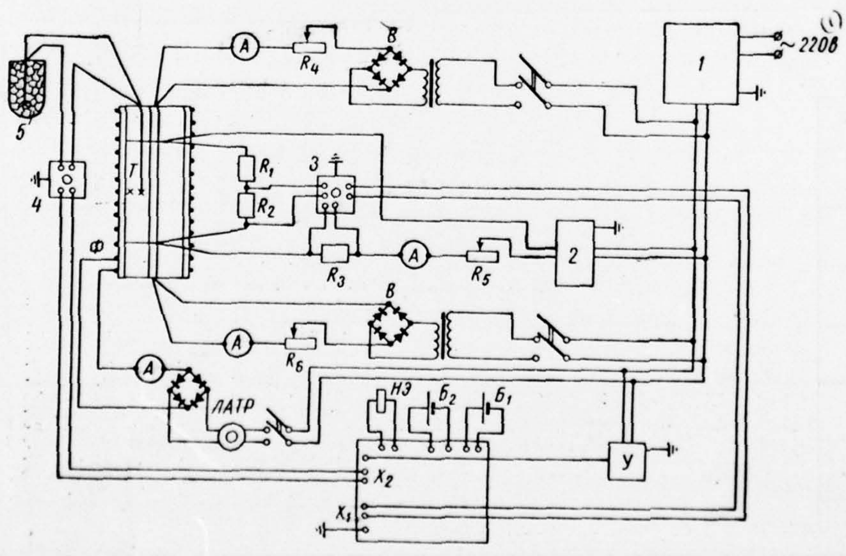

Fig. 4.

Fig. 4. The diagram of the measuring bench: 1 - the stabilizer of direct current 2 SND2; 2 - the stabilizer of the direct current of P-136; 3, 4 - nonthermoelectric current switches (plant "Etalon", type PB-12v); 5 - Dewar flask for cold ends; $R_1 = 10^5$ ohm, $R_2 = 10^3$ ohm and $R_3 = 0.1$ ohm is specimen resistor coils of II class; R_4, R_5 and R_6 - control resistors; ~~R~~ P[П] - a potentiometer of the type of R308 with amplifier of the type of F305.I; NE - normal cell/element; B_1 and B_2 - the battery of the supply of potentiometer; LATR - an autotransformer of the type of RN~~R~~O-250-2; V - semiconductor rectifiers; ~~Vol.~~ T - hot end; ~~F~~ F - backgrourd heater.

Key: (1) volts.

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The basic sources of systematic errors are a difference in the thermal resistance, arrange/located on the external surface of specimen/sample (because of the inadequacy of contact with the internal surface of the housing of background heater), the dissimilarity of the thermal resistor/resistances of measuring thermocouples with specimen/sample, and also the difference in the temperature conditions of measurement and graduation of thermocouples. The indicated sources of errors lead to the fact that the initial temperature field of specimen/sample is uneven. Subsequently the resulting error, caused by these factors, we will

call an error in the heterogeneity of temperature field.

For the exception/elimination of this error, was utilized the principle of the superposition of temperature fields according to which, the stationary temperature fields, caused by the different constantly acting sources, store/add up themselves. Hence appears possibility to eliminate an error in the heterogeneity systematically: first necessary to record stationary temperature field with switched off basic and guard heaters, and then to include/connect heaters and to record new stationary temperature field. In working formula it is necessary to substitute the obtained differences in the temperatures, which do not contain errors in the heterogeneity. There are, at least, two possibilities to check the validity of the aforesaid. First, the absence of the account of an error in the heterogeneity leads to the fact that the values of thermal conductivity, measured in four radial directions, differ by 5-6o/o. Upon consideration of error, this difference does not exceed 2o/o. In the second place, measurements show that the heterogeneity of field with switched off basic and guard heaters is retained identical at all temperature levels. This means that the sources of nonuniformity are constant for one set of experiments, which is characterized by the invariability of the assembly of specimen/sample and guard cylinders in the housing of background heater.

Another systematic error can be caused by heat dissipation on the electrodes of the measuring thermocouples which lead to an error of measurement of value q, substituted in working formula, and to an error of measurement of temperature in connection with the disturbance of temperature field in measuring point. By our case these errors do not exceed 0.1 and 0.07o/o respectively [1].

FOOTNOTE [1]. See [Russian] page 187. ENDFOOTNOTE.

As will show the calculations, nonexcluded residue/remainders of systematic errors were equal because of: heat dissipation from the end/faces of specimen/sample 0.18o/o; heat dissipation from the end/faces of basic heater 0.03o/o; heat dissipation on the coupling copper potentiometric lead/ducts of basic heater 0.04o/o; inflow of heat from the current copper jumpers of basic heater 0.07o/o; heat dissipation on the electrodes of measuring thermocouples 0.03o/o; due to the inaccurate determination of the length of the working section of the basic heater and, consequently, also its power 0.1o/o.

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During the calculation of random errors, nonexcluded

residue/remainders of systematic errors are considered as random with normal distribution.

A relative random error in the measurements is calculated from formula

$$\frac{\Delta\lambda}{\lambda}=\sqrt{\left(\frac{\Delta q}{q}\right)^2+\left[\frac{\Delta\left(\ln\frac{r_2}{r_1}\right)}{\ln\frac{r_2}{r_1}}\right]^2+\left(\frac{\Delta L}{L}\right)^2+\left[\frac{\Delta(t_2-t_1)}{t_2-t_1}\right]^2}.$$

The power of the basic heater is measured by potentiometer method with error 0.01o/o. Taking into account the enumerated nonexcluded residue/remainders of systematic errors $\Delta q/q$ = 0.15o/o.

For transparent bodies (polymethyl methacrylate, glass), which are the basic subjects of investigation, the radii $r_1 \simeq 7$ mm and $r_2 \simeq$ 17 mm are determined with the help of the microscope of UIM=21 with

error 0.025 mm. Consequently, $\frac{\Delta \ln \frac{r_2}{r_1}}{\ln \frac{r_2}{r_1}} = 0,4\%.$

In order to ensure the conformity of the measured radii and positions of thermocouples, into the conical part of the blind hole (Fig. 5) are placed copper filings for temperature balance in the zone of the arrangement of thermojunction. This makes it possible to relate the measured temperature to the point, arrange/located in the center of opening/aperture.

The length L = 120 mm of the investigated specimen/sample is determined with error 0.25 mm, i.e., $\Delta L/L$ = 0.2o/o.

Differences in temperatures t_2-t_1 = 10 deg are measured by differential copper-constantan thermocouples with error $\Delta(t_2-t_1)/t_2-t_1$ = 0.5o/o.

Thus, the calculated maximum random error in the measurements of thermal conductivity will be 1.1o/o.

At installation is measured the thermal conductivity of polymethyl methacrylate in temperature range 90-300°K. Measurements are carried out at three different powers of central heater, which give, correspondingly, three different calculated jump/drops in specimen/sample -5; 7.5 and 10 deg, i.e., dependence $\lambda = f$ (T) was

obtained for three calculated the temperature differentials.

The comparison of experimental results shows that the systematic errors, connected with heat dissipation from central heater, are absent. Everything three runs of measurements were considered as equally accurate, since the scatter of experimental points for all three cases does not exceed the limits of an error in the method.

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Fig. 5. Diagram of the stopping up of the thermocouples: 1 - thermojunction; 2 - filling made of copper filings; 3 - the electrodes of thermocouples; 4 - ceramic diplex tube; 5 - the investigated specimen/sample.

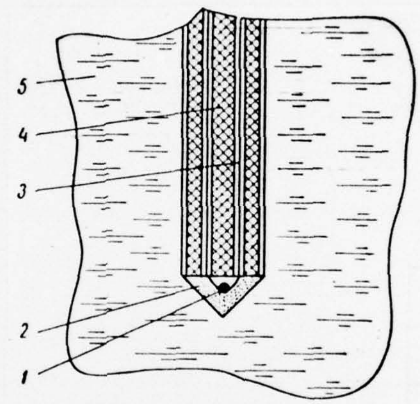

Fig. 5

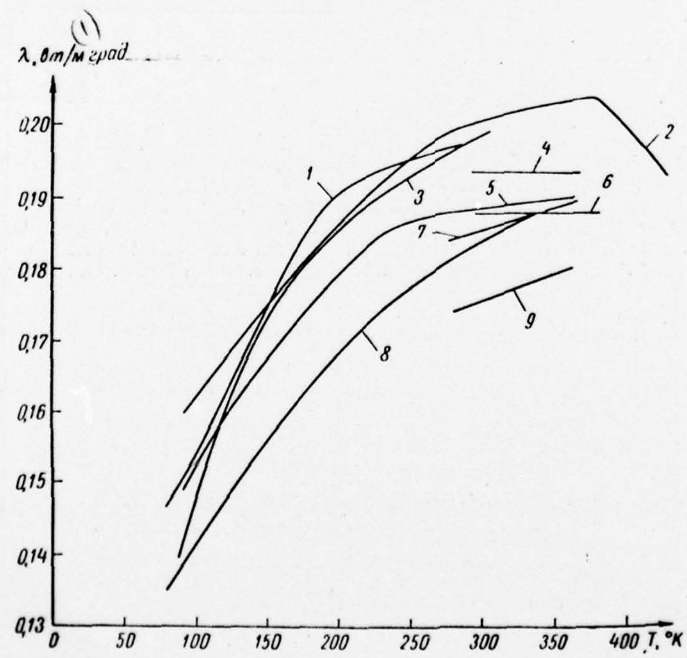

Fig 6

Fig. 6. Dependence of the thermal conductivity of polymethyl methacrylate on temperature according to the data of the works: 1, 8. [3]; ~~1~~ 2 - [1]; 3 - according to our data; 4 - [7]; 5 - [2]; 6 - [8]; 7, 9. [9].

Key: (1). W/m deg.

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Processing the findings on the method of least squares leads to the following dependence of thermal conductivity on the temperature: $\lambda = 0.224 - (7.550/T)$.

A root-mean-square error of measurement of thermal conductivity will turn out to be equal to 1.0o/o. The dependence of thermal conductivity on temperature is shown in Fig. 6 (is curve 3). As is evident, the findings will agree well with literature.

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